CARDIAC PHYSIOLOGY OF THE SCORPION PALAMNAEUS BENGALENSIS C. KOCH [1]

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The nature of heart-beat among arthropods has been studied by several workers (Prosser, 1942; Needham, 1950; Krijgsman, 1952). It has been observed in Crustacea and Insecta that the origin of heart-beat in each class is of varied types and has no relationship with the taxonomic classification. Among the arachnids, *Limulus* has a myogenic heart-beat in the young which becomes neurogenic in the adult (Prosser, 1942; Krijgsman, 1952) and the heart-beat of spiders is neurogenic (Rijilant, 1933). Even though Police (1902) indicated the presence of an epicardiac nerve on the heart of scorpion, the heart-beat of the scorpion, *Palamnaeus bengalensis* has been reported by Kanungo (1955) to be myogenic. It is of interest to find that, also in Arachnida as in Crustacea and Insecta, the nature of heart-beat is not of a single type. The hearts of arachnids are poorly understood and the present work is a detailed study of the physiology and pharmacology of the heart of *Palamnaeus bengalensis*.

Materials and Methods

Scorpions freshly collected from their natural habitat (Lal and Kanungo, 1953) were used for these experiments. They were lightly chloroformed and immediately dissected in a saline containing sodium chloride, 0.65 gm.; potassium chloride, 0.03 gm., and calcium chloride, 0.03 gm.; in 100 ml. of distilled water. The saline, which was prepared fresh before the experiments, was maintained at pH 6.3 using phosphate buffer, as the haemolymph of the scorpion was found to be on the acid side of neutrality in agreement with Maluf's (1939) statement. The heart was exposed fully *in situ* by carefully cutting the terga at the sides and removing them. Isolated heart preparations were made in petri dishes containing the saline. Effect of pH, temperature and drugs on the heart-beat were observed on hearts both *in situ* and isolated. Nearly 150 heart preparations have been made for various drug experiments.

Anatomy of the Heart

Like that of *Buthus* (Parker and Haswell, 1940), the heart of *P. bengalensis* is eight-chambered, spongy and muscular. It is enclosed in a pericardium and is

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held in its position between the two lobes of the liver by eight pairs of alary muscles. It is 2.5 cm. long in a medium-sized scorpion with a body length of approximately 5 cm. A thin-walled anterior aorta arising from the heart bifurcates on the oesophagus. A thin-walled posterior aorta proceeds to the tail.

General Properties of the Heart-Beat

Hearts both *in situ* and isolated showed a high degree of automaticity; contractions occurred simultaneously throughout the myocardium and following one another in a regular uninterrupted sequence rhythmically. Simultaneous contraction of the scorpion heart had been reported earlier (Du Buisson, 1925). When first isolated, the rate of beat of the heart was irregular and slow, but it became normal after about 5 minutes, and showed a little acceleration in the rate of beat as compared with that of hearts *in situ*. The rate of beat of intact hearts was 50–54/minute at room temperature (25–27° C.). Cutting of the alary muscles *in situ* resulted in a slight increase of the rate to 56–62/minute, which was the same as that of isolated hearts. It appears, therefore, that even though the property of automatic movement lies in the muscles of the heart itself, the regulation of the rate of beat is effected by alary muscles. The rate of isolated heart preparations remained normal for 10–12 hours after which it decreased and the amplitude fell gradually. Mechanical stimuli like shaking the saline or pressing the heart with a needle temporarily inhibited the heart-beat. After 2–4 minutes, an acceleration in the rate was observed. Excised pieces of the heart beat for about 4–5 minutes. In all preparations, the anterior end stopped first and the posterior end later, suggesting that the pace-maker of the heart is situated at the latter end.

Course of Circulation

As stated above, isolated hearts beat with the anterior and posterior ends contracting and relaxing simultaneously. During diastole the heart shortens in length and bulges and the haemolymph flows in through the paired ostia. During systole, the heart extends lengthwise, the ostial valves close and the haemolymph is expelled at both the ends. A freshly isolated heart was placed in a dry watch glass in such a manner that the two ends were at a higher level than the middle region. A drop of neutral red was put at the center of the watch glass. The heart continued to beat and neutral red was seen flowing out at both the ends.

Effect of Temperature

Isolated hearts in petri dishes containing the saline were kept at different temperatures in an incubator and their rates were noted. An upper limiting rate of 80–85/minute was observed at 42° C., above which beating ceased permanently. The lower limiting rate on cooling was 4–5/minute at 5° C. Below this temperature the heart ceased beating but recovered when the temperature was increased.

Effect of pH

Separate stocks of the same saline solution were prepared by buffering with phosphate buffer between pH 5.5 and pH 7.5 and the hearts were kept in these

salines. The heart remained active between pH 6.1 and pH 6.5. With increase or decrease of the pH of the saline beyond this range, depression of the heart rate occurred.

Effects of Drugs

Fresh dilutions of 10^{-3}, 10^{-4}, 5×10^{-4}, 10^{-5}, 5×10^{-5}, and 10^{-6} of various drugs were made in the saline before each set of experiments. Both intact and isolated hearts were bathed side by side with one of the diluted drugs to compare their effects on the heart-beat in isolated and *in situ* preparations. No difference between isolated and intact hearts was observed. Mechanical shock to the heart was avoided as far as possible. The drug was sucked out with a pipette, the heart

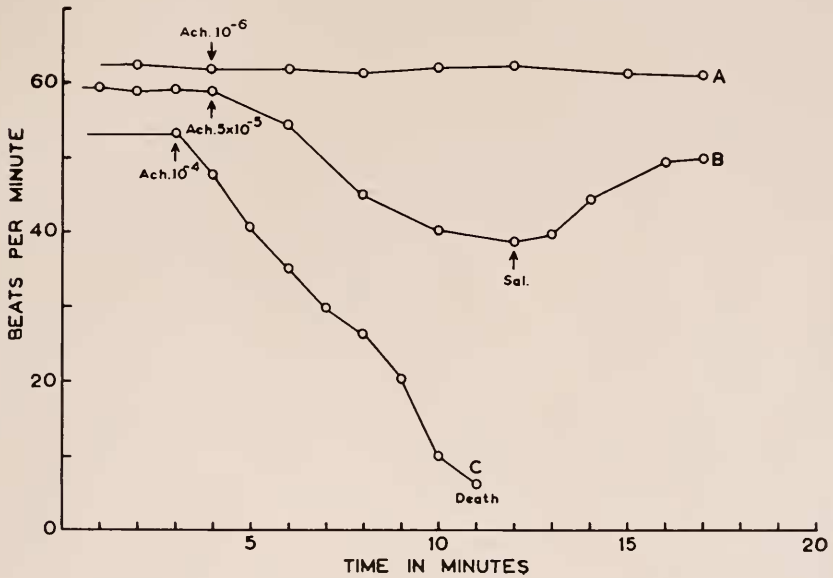

Figure 1. Effect of acetylcholine on the heart of *P. bengalensis*. Ach., acetylcholine; Sal., saline.

washed with the saline three times and the fresh drug added slowly. Recordings of the heart rate were made following the methods of Jones (1954). Three recordings, one minute each in length, were made one minute after adding the drug.

Acetylcholine more dilute than 5×10^{-5} had no effect on the heart rate. Concentrations of 5×10^{-5} or stronger depressed the heart rate; the time taken for depression was inversely proportional to the concentration of the drug (Fig. 1). There was a gradual weakening of the strength of beat, reduction in the amplitude, rest-pauses and sporadic irregularities in 5×10^{-5} or stronger concentrations. In no case was there any acceleration before the depression. Neither did the beat recover if the heart was left in the drug. However, all such hearts recovered after they were washed with the saline, but the normal rate of beat was never reached. Some hearts showed tolerance to the drug up to 10^{-4} after prior treatment with more dilute solutions and gradually increasing concentrations (Fig. 2D).

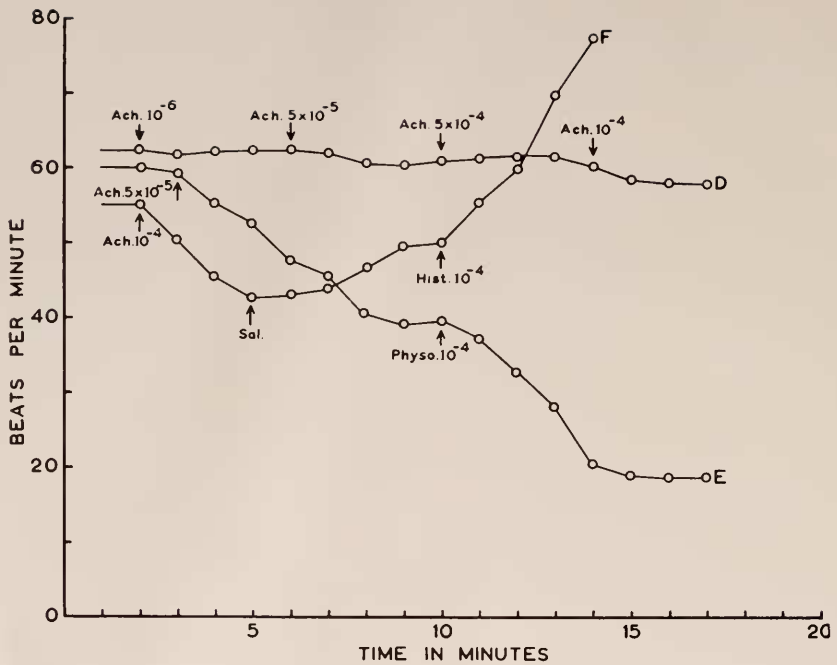

FIGURE 2. Effects of various drugs on the heart of *P. bengalensis*. Ach., acetylcholine; Adr., adrenaline; Atr., atropine; Hist., histamine; Physo., physostigmine; Sal., saline.

Physostigmine at 10^{-4} or stronger did not by itself show any appreciable effect on the heart rate. However, application of acetylcholine to the heart, after treatment with physostigmine, potentiated the effect of acetylcholine (Fig. 2E).

Histamine at 10^{-4} or stronger accelerated the heart rate to a maximum of 85/minute and this effect was reversible on washing with the saline. The time taken for the heart to reach the maximal rate in different dilutions was directly proportional to the dilutions of the drug. It antagonized acetylcholine action, and hearts collapsing under the treatment with acetylcholine could be revived by this drug. Such hearts also beat at 85/minute (Fig. 2F).

Adrenaline at 10^{-5} or stronger accelerated the heart rate to about 75/minute and this effect was reversible.

TABLE I

Comparison of the effects of drugs on the hearts of Limulus and P. bengalensis

	Ach.	Atropine	Adrenaline	Ether	Histamine	Physostigmine	Chloroform
*Limulus**	+	+	+				
P. bengalensis	−	−	+	0	+	0	0

+, excitation; −, inhibition; 0, no effect.
* Krijgsman, 1952.

Atropine at 5×10^{-4} or stronger inhibited the heart rate reversibly.

Half-saturated and fully-saturated aqueous solutions of *ether* had no observed effect on the heart-beat.

Chloroform had no observed effect on the heart-beat.

It was found in all the cases that the drug-treated hearts recovered after washing with the saline. A quicker recovery of the heart was attained by using warm saline which was added slowly to the heart container. The time taken for such recovery varied from five to fifteen minutes.

Table I gives comparatively the effects of various drugs on the hearts of *Limulus* and *P. bengalensis*. Even though Table I does not indicate the effect of ether on the neurogenic heart of *Limulus*, it may be mentioned here that ether inhibits neurogenic hearts in low concentrations (Needham, 1950).

Haemolymph Pressure

Bleeding occurred when incisions were made at pedipalpi, abdomen and tail regions; this indicates positive haemolymph pressure throughout the body. By inserting capillaries in continuation with U-tubes, actual pressure was found to be 6 mm. of saline at the pedipalpi and at the abdomen.

Discussion

The pharmacology of the scorpion heart resembles that of the crustacean, *Daphnia* (Baylor, 1942) and the vertebrates, and has no resemblance to that of *Limulus*. According to Prosser *et al.* (1950), the hearts of arthropods are of non-innervated myogenic, innervated myogenic and neurogenic types, which description is based mainly on acetylcholine effect. Needham (1950) classified the crustacean hearts into two categories, myogenic and neurogenic, by taking several factors into consideration. The heart of *P. bengalensis* in showing (1) autonomous rhythmicity with contractions developing simultaneously throughout the myocardium, (2) insensitiveness to ether, and (3) inhibition by acetylcholine indicates that the nature of its beat or that of its pacemaker is innervated myogenic. The epicardiac nerve reported by Police (1902) appears to be either extrinsic or regulating in function.

Summary

1. The heart of *P. bengalensis* beats continuously at a rate of 50–62/minute at a temperature of 26° C. The contraction is developed simultaneously throughout the muscle.

2. Acetylcholine and atropine depress the heart-beat and their actions are reversible. Physostigmine potentiates the effect of acetylcholine.

3. Ether and chloroform have no effect on the heart-beat.

4. Histamine and adrenaline accelerate the heart-beat and their effects are reversible on washing with saline.

5. The haemolymph pressure is 6 mm. of saline.

6. It is concluded that the pace-maker of the heart of *P. bengalensis* is of the innervated myogenic type.

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